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Inferred ontology concepts alignment using instances and an external dictionary

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Abstract

In this paper, a novel approach using Description Logic (DL) based inference rules, for ontology matching is presented. Alignment concerns ontology concepts, with the application of similarity measures to perform concepts and instances relationship alignments. Moreover, external knowledge, in the form of WordNet dictionary is then used to solve usual matching problems encountered with synonyms, polesemy, homonyms, etc. Illustrative examples are then presented to support the developed approach.
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1. Introduction

The representation of Ontology is used by many applications to represent a given domain knowledge, such as: semantic web services, database integration, peer-to-peer systems, social networks, etc. [1]. However, in evolving systems such as the semantic web, different parties would, in general, adopt diverse ontologies[2]. Before being able to combine similar ontologies, a semantic and structural mapping between them has to be established. The process of establishing such a mapping is called ontology alignment[3].

Matching ontologies will become a cornerstone in the realisation of the semantic web vision, and several automatic or semi-automatic ontology alignment tools have been proposed e.g.[2 4]. In the literature there are several ontology matching methods, and most of them are established on similarity measures between the entities to assess the alignment sets for the ontology matching system[5], for instance Coma++[6]. The value of these measures, often determines the similar/dissimilar entities of the matched ontologies. In other words, these measures define just the equivalence and disjunction relations, which do not address on ontology matching issues, such as interoperability or data inte-

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gration. In the present paper, the focus is put on the discovery of the equivalence/disjunction relations as well as the subsumption relations between the concepts of ontologies to align.

This paper is organized as follows: Section 2 defines the ontology and Description logic (DL) used in this paper. Section 3 discusses the matching process, where Section 4 describes the first level of the proposed approach. The paper will then be ended by a conclusion and some perspectives describing future work directions.

2. Premilinaries

Definition 1. (Ontology) The ontology is defined here as the tuple: $O_i := (D, A, KB, Lex)$ where D represents the core ontology, A the L-axiom system, KB the knowledge base, and Lex is the lexicon used. Other otology descriptions may be found in[7] but in order to describe the different techniques handled for the matching task, the definition of ontology given by the Karlsruhe Ontology Model[8] seems to be the most advised.

Definition 2. (Description Logic DL) The Description Logic languages is considered as the core of knowledge representation systems, viewing both the structure of DL knowledge base and its associated reasoning services[9]. The knowledge base of DL is expressed by a pair $< T, A >$, where T is a terminological box (TBox), a finite set containing the definition of concepts and roles. The concepts definition is expressed by a terminological axioms of the forms $C_1 \subseteq C_2, C_1 \supseteq C_2, C_1 \equiv C_2$, or $C_1 \perp C_2$, where C_1, C_2 are atomic concepts. Furthermore, A the assertional knowledge (ABox) describes individuals by naming and specifying them to its concepts and roles. Several ABoxes may be associated with a same Tbox, as well as the association function used in this paper. DL is characterized also by an interpretation, consisting in a non-empty set $\triangle$ called the interpretation domain, composed of individuals set, expressed here as instances sets I_i and an interpretation function assigning to each atomic concept A, a set of individuals $A^I \subseteq \triangle$, as well as to each atomic binary relation B, a sets of pairs of individuals $B^I \subseteq \triangle x \triangle$[9].

3. Ontology Matching

The matching process expresses an alignment of two ontologies[10] O_1 and O_2 . The Alignment methods require the assessment of the similarity and/or the relation among the concepts and between the relations of ontologies to align. These concepts C and the relations B can be presented as a structure $D := (C, <_C, F, B, <_B)$ of O, where the concept hierarchy or taxonomy is represented by a partial order $<_c$ on C, correspond to set-theoretic relations $Rel = \{\equiv, \subseteq, \supseteq, \perp\}$. The function signature $F : B \longrightarrow CxC$ restricts the model to binary relations, where $F(B_1) = \{dom(B_1), rang(B_1)\}$, for $B_1 \in B$, $dom(B_1)$ symbolized the domain and range $ran(B_1)$, which is treated as an instances of the concepts in the first level and a concept in the second one. The relation hierarchy defined by a partial order $<_B$ on B as:

$$B_1 <_B B_2 \quad Iff \quad (dom(B_1) <_C dom(B_2) \quad and \quad rang(B_1) <_C rang(B_2)) \tag{1}$$

In order to discover the relation between these concepts and binary relations, we start by comparing their instances, for allowing grounding during this operation[2]. These instances (if they exist) are expressed as a structure $KB := (C, B, I, i_C, i_B)$; where the sets C and B as presented before; I is a set of instances, $i_C : C \longrightarrow 2^T$[11] is the association function, associate every concept such as C_1 and $C_1^{'}$ to its instances in I; as well as $i_{B_1} : B_1 \subseteq 2^T$, with $B_1 \subseteq i_{C_1^{'}} x i_{C_1}$ for all $B_1 \in B$. Afterwards, the terminological methods are used to compare the names of instances (relationships and entities in below sections) presented with $Lex := (S_C, S_B, S_I)$. Where, the identifier A_i denotes the three sets S_C, S_B, S_I, express respectively the names of instances, relations, and concepts. This identifier is associated to an axiom by an associate function named x in L-axiom $A := (A_i, x)$.

To illustrate the proposed alignment process two ontologies O_1 and O_2 describing *Human* and *Person*, shown as graphical hierarchies in Fig. 1. are presented. Rectangular boxes indicate concepts, the octagons design properties, the instances are depicted as ellipse and the hierarchy relations as solid arrows. The incoming arrow of relation comes from its domain and an outgoing arrow to its range. Alignments are represented by dotted angle connectors.

4. Level 1 of the proposed alignment algorithm

In this level, we first compare the instances of concepts to deduce the relations among them. After, from these relations, we will infer other relations and align the binary relations.

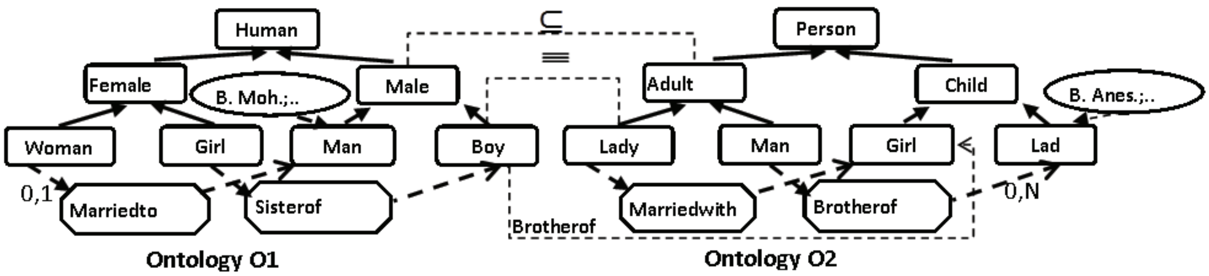

Fig. 1. Ontology alignment example

1. concepts alignment: In this part of algorithm, the strings $S_{I_{C_1}}$ of I_{C_1} and $S_{I_{C_2}}$ of I_{C_2}, will be normalized[12] then compared by using the metric of similarity n-gram, which controls the size of the lexicon and maintain a reasonable threshold for every composed terms (names). The result will be one of the following relations: $S_{I_{C_1}} = S_{I_{C_2}}$; $S_{I_{C_1}} \subseteq S_{I_{C_2}}$; $S_{I_{C_1}} \supseteq S_{I_{C_2}}$; $S_{I_{C_1}} \neq S_{I_{C_2}}$.

To deduce the relation between C_1 and C_2, DL characteristics are used, upon which the ontology is expressed. Where the meaning of each ontology element, is provided by an interpretation I, for example, in Fig.1. $\triangle_1 = \{B.Moh, B.Anes, G.Billel, G.Hichem\}$ of O_1; $\triangle_2 = \{B.Anes, G.Billel\}$ of O_2. and the association functions i_C, which associate to $O_1(O_2)$ the concepts $C_1, C_1^{'}(C_2, C_2^{'})$ named respectively *Man* and *Boy*(*Man* and *Lad*) to the sets of instances names $I_{C_1} = \{B.Moh, G.Billel, G.Hichem\}$ and $I_{C_1^{'}} = \{B.Anes\}(I_{C_2} = \{G.Billel\}$ and $I_{C_2^{'}} = \{B.Anes\})$. Therefore to align the concepts we have:

- $C_1 \equiv C_2$, if $C_1^I = C_2^I(I_{C_1} = I_{C_2})$this relation ($\equiv$) allows to add the two relations $C_1 \subseteq C_2$ and $C_1 \supseteq C_2$, as well as the inverse, which is justified and proven by inference[13]. These results are organized in the form (C_1, C_2, Rel), to build the alignment ontology called Alignment ontology (Ao), which will be used as input in the next algorithm's steps. When, the ontologies to align do not contain any instances, a human must intervene to construct Ao. In our example, the sets $I_{C_1^{'}} = \{Boy\}$ and $I_{C_2^{'}} = \{Lad\}$ are equivalent, so $Ao = \{(Boy, Lad, \equiv)\}$.
- $C_1 \subseteq C_2$ if and only if $C_1^I \subseteq C_2^I(C_1 \supseteq C_2)$, i.e. if $I_{C_1} \subseteq I_{C_2}(I_{C_1} \supseteq I_{C_2})$ then $C_1\ of\ O_1\,(C_2\ of\ O_2)$ can be subsumed by $C_2\ of\ O_2\,(C_1\ of\ O_1)$ or not and vice versa. Further, The concepts $C_1, C_2\,(C_1 \perp C_2)$ are disjoint, if $C_1^I \cap C_2^I = \oslash$ (design the empty set), i.e., iff $I_{C_1} \neq I_{C_2}$. This is because the concepts of ontologies to align, may be insufficiently detailed in terms of instances. These cases will construct the temporary alignment ontology At, which will be treated in level 2. Since the instance $\{G.Billel\}$ of I_{C_2} belong to I_{C_1} in Fig. 1., so $I_{C_1} \supseteq I_{C_2}$ and the tuple $(Man, Man, \supseteq)$ will the first element of the ontology At.

2. Aligning relationships: In order to prove the results provided by the comparaison of the Binary relations of the Ao concepts, such as C_1 and C_2 in their original ontologies, we use the role restriction of DL[9]. We suppose that the concept C_1 (C_2) is related with the concept $C_1^{'}$ ($C_2^{'}$) of O_1 (O_2) by the binary relation B_1 (B_2), restricted by $(R_1)_{C_1}^{C_1^{'}}$ ($(R_2)_{C_2}^{C_2^{'}}$) mentioned in equation (2). Further, the concepts C_1 and C_2 can be align, at first, with one of the relation from the set $Rel_1 = \{\equiv, \subseteq, \supseteq, \perp\}$ in this base, but after one iteration of the comparaison of the binary relation B_i can be added to this set, and becomes $Rel_2 = \{\equiv, \subseteq, \supseteq, \perp, B_i\}$.

$$(R_1)_{C_1}^{C_1^{'}} = \{(x, y) \in \triangle x \triangle \mid (x, y) \in R_1^I \wedge x \in C_1^{'I} \wedge y \in C_1^I\}; \qquad (R_2)_{C_2}^{C_2^{'}} = \{(a, b) \in \triangle x \triangle \mid (a, b) \in R_2^I | a \in C_2^{'I} \wedge b \in C_2^I\} \quad (2)$$

We suppose here that $y = I_{C_1}$ and $b = I_{C_2}$, so from equation (2) the role restriction $(R_1)_{C_1}^{C_1^{'}}$ ($(R_2)_{C_2}^{C_2^{'}}$) interprets the set of instances x (a) of $C_1^{'}$ ($C_2^{'}$) that are in relationship with instances y (b) belonging to the set of instances of C_1 (C_2). First, if $C_1 \equiv C_2$ then $y = b$, and when we replace: y by b and C_1 by C_2 in $(R_1)_{C_1}^{C_1^{'}}$, thus, b by y and C_2 by C_1 in $(R_2)_{C_2}^{C_2^{'}}$, of equation (2); we can write equation (3). In addition, the binary relations can have the Number restrictions, restrict the sets cardinality of R_1 and R_2 as expressed in equation (4) and (5) respectively.

$$(R_1)_{C_2}^{C_1^{'}} = \{(x, b) \in \triangle x \triangle \mid (x, b) \in R_1^I \wedge x \in C_1^{'I} \wedge b \in C_2^I\}; \qquad (R_2)_{C_1}^{C_2^{'}} = \{(a, y) \in \triangle x \triangle \mid (a, y) \in R_2^I \wedge a \in C_2^{'I} \wedge y \in C_1^I\} \quad (3)$$

$$(min_1R_1)^I = \{y \in \triangle^I \mid |\{x|(x,y) \in R_1^I\}| \geq min_1\}; \qquad (max_1R_1)^I = \{y \in \triangle^I \mid |\{x|(x,y) \in R_1^I\}| \leq max_1\} \tag{4}$$

$$(min_2R_2)^I = \{b \in \triangle^I \mid |\{a|(a,b) \in R_2^I\}| \geq min_2\}; \qquad (max_2R_2)^I = \{b \in \triangle^I \mid |\{a|(a,b) \in R_2^I\}| \leq max_2\} \tag{5}$$

$$(min_1R_1)^I = \{b \in \triangle^I \mid |\{x|(x,b) \in R_1^I\}| \geq min_1\}; \qquad (max_1R_1)^I = \{b \in \triangle^I \mid |\{x|(x,b) \in R_1^I\}| \geq max_1\} \tag{6}$$

$$(min_2R_2)^I = \{y \in \triangle^I \mid |\{a|(a,y) \in R_2^I\}| \geq min_2\}; \qquad (max_2R_2)^I = \{y \in \triangle^I \mid |\{a|(a,y) \in R_2^I\}| \leq max_2\} \tag{7}$$

Where, " | . | " symbolizes the cardinality of a set in each equation, and the at-least restriction $min_1R_1(min_2R_2)$ designs the lower bound on the number of the instances y (b) that have the binary relation $B_1(B_2)$ with the instance x (a) of C_1 (C_2). However the at-most restriction max_1R_1 (max_2R_2) indicates the upper bound.

From equation (5), $(C_2, C_1^{'}, B_1)$ and $(C_1, C_2^{'}, B_2)$ will be inserted in *Ao* with the same restriction. Then, from (1), if the concepts $C_1^{'}$ and $C_2^{'}$ exist in *Ao*, this mean: If $C_1^{'} \subseteq C_2^{'}$ then $B_1 \subseteq B_2$; and/or If $C_1^{'} \supseteq C_2^{'}$ then $B_1 \supseteq B_2$, because we can replace ($\equiv$) by a both ($\subseteq, \supseteq$). So $(B_1, B_2, \subseteq)$ and/or $(B_1, B_2, \supseteq)$ will add to *Ao*.

Secondly, if $C_1 \subseteq C_2(C_1 \supseteq C_2)$ then $y \subseteq b(y \supseteq b)$, signifies that the set of instances of $y(b)$, belong to the set $b(y)$, which implies that the instances of set $x(a)$ have a relation with the instances of set $b(y)$, they also have the same relation with those of $y(b)$ belonging to $b(y)$, and $(C_2, C_1^{'}, B_1)((C_1, C_2^{'}, B_2))$ with $(B_1, B_2, \subseteq)$ if $C_1^{'} \subseteq C_2^{'}$ ($(B_1, B_2, \supseteq)$ if $C_1^{'} \supseteq C_2^{'}$) will be inserted in *Ao* as explain in the previous paragraph. Though, if $C_1^{'} \supseteq C_2^{'}$ ($C_1^{'} \subseteq C_2^{'}$), we obtain and insert the fuzzy result in this base such as: $(C_1^{'}, C_2^{'}, \&)$, and the set of relations becomes $Rel3 = \{\equiv, \subseteq, \supseteq, \perp, B_i, \&\}$.

However, when the number restriction exists, the treatment will be: If $(C_1 \equiv C_2 \vee C_1 \subseteq C_2 \vee C_1 \supseteq C_2)$ then the same results cited above will hold, because when y is replaced by b in equation (4) as well as when $C_1 \subseteq C_2$; and b replaced by y in equations (5), we obtain respectively equations (6) and (7) as well if $C_1 \supseteq C_2$.

When this is applied to the concept *"Lad"* of O_2, that have the relation *brotherof* with *Girl*, with $(0, N)$ restriction, we obtain *Lad brotherof Girl*. In addition from the *Ao* we can write (*Boy* $\equiv$ *Lad*), and insert (*Lad,Girl,brotherof*) to this base. Then from the first level, we obtain $Ao = \{(Boy, Lad, \equiv), (Boy, Girl, brotherof)\}$.

5. Level 2 of the proposed alignment algorithm

At this level, we first validate then insert in *Ao* the aligned concepts of *At*, by applying the below terminological methods on names of concepts as follow:

- If $((C_1 \subseteq C_2)$ or $(C_1 \supseteq C_2))$ and $(S_{C_1} \equiv S_{C_2})$ then $C_1 \equiv C_2$
- If $(C_1 \subseteq C_2)$ and $(S_{C_1} \subseteq S_{C_2})$ then $C_1 \subseteq C_2$; If $(C_1 \supseteq C_2)$ and $(S_{C_1} \supseteq S_{C_2})$ then $C_1 \supseteq C_2$
- If $(C_1 \supseteq C_2)$ and $(S_{C_1} \equiv S_{C_2})$ then $C_1 \& C_2$; If $(C_1 \subseteq C_2)$ and $(S_{C_1} \supseteq S_{C_2})$ then $C_1 \& C_2$
- If $(C_1 \perp C_2)$ and $(S_{C_1}\ Rel\ S_{C_2})$ then $C_1 Rel C_2$

The second item involves that the alignments $(C_1 \subseteq C_2)$ and/or $(C_1 \supseteq C_2)$ will be deleted from the *At*, and will be inserted into *Ao* with $(C_1 \equiv C_2)$ provided from the first item. The third constraint means that (C_1, C_2) are overlapped because we can deduce $(C_1 \supseteq C_2)$ or $(C_1 \subseteq C_2)$, which will be deleted from *At*, then added to *Ao* $(C_1 \& C_2)$. In contrast in the last constraint the relation *Rel* mentioned above will be retained and $(C_1 Rel C_2)$ will be inserted to *Ao*, but $(C_1 \perp C_2)$ will removed from *At*, because the results of the first step, are linked to lack of instances.

Afterwards, terminological methods will be used to compare the names of the neighboring concepts of C_1 and C_2 existing in *Ao*, with them in their originals ontologies. These methods give more pertinent results because concepts neighbors have more chance to be similar[2]. Therefore, it can not be assumed with certainty that two entities are dissimilar because they have different names(synonyms), or that they are equivalent if they have the same name(homonyms). To resolve this problem, a background knowledge in the form of WordNet dictionary[14] is used by the system BRMAP (Background Raisoner MAPping)[12], to discover the relation among the concepts $C_1^{'}$ and $C_2^{'}$.

Here, we suppose that Wordnet is hierarchically organized as $W(S, \leq, Ag, g)$, where S is a set of synsets $\{s_1, s_2, , s_i\}$(i is a positive integer), and an annotate function Ag associates the gloss g to each synset. Furthermore, the relations $\leq$ between concepts s_1, s_2 may be presented in the following logical relations[15] as: $s_1 \subseteq s_2$; $s_1 \supseteq s_2$; $s_1 \equiv s_2$; $s_1 \perp s_2$.

The concept neighbors are those who have one of the set's relation Rel_2, for example: $C_1^{'}$ is the neighbor of C_1 in O_1 iff $C_1\ Rel_2\ C_1^{'}$, and the neighbor of C_2 in O_2 is $C_2^{'}$ iff $C_2\ Rel_2\ C_2^{'}$. Now, we start by aligning the neighbours that have the binary relation B_i with C_1 and B_j with C_2 as: If $((C_1 \equiv C_2)$ or $(C_1 \subseteq C_2))$ and $(C_1\ B_i\ C_1^{'})$ then $\left(C_2\ B_i\ C_1^{'}\right)$;

If (($C_2 \equiv C_1$) or ($C_2 \subseteq C_1$)) and ($C_2\ B_j\ C_2'$) then ($C_1\ B_j\ C_2'$); and insert from above:(C_2, C_1', B_i) and/or (C_1, C_2', B_j) in Ao. Further, when we deduce that ($C_1' \subseteq C_2' or C_1' \supseteq C_2'$) ($B_i \subseteq B_j or B_i \supseteq B_j$) is then also added in Ao respectively.

The names are compared to synsets by using the n-gram measure, the distance between these synsets is measured by using the hypernym structure included in the Pellet[16] reasoner integrated in BRMAP and produce: If ($S_{C_1'} \equiv s_1$ and $S_{C_2'} \equiv s_2$ and $s_1 \equiv s_2$) then $S_{C_1'} \equiv S_{C_2'}$, which implies the relation $C_1' \equiv C_2'$; If ($S_{C_1'} \equiv s_1$ and $S_{C_2'} \subseteq s_2$ and $s_1 \equiv s_2$) then $S_{C_1'} \subseteq S_{C_2'}$, which involves $C_1' \subseteq C_2'$; If ($S_{C_1'} \equiv s_1$ and $S_{C_2'} \supseteq s_2$ and $s_1 \equiv s_2$) then $S_{C_1'} \supseteq S_{C_2'}$, to deduce $C_1' \supseteq C_2'$, and we obtain $C_1' \perp C_2'$ If ($S_{C_1'} \equiv s_1$ and $S_{C_2'} \perp s_2$ and $s_1 \equiv s_2$).

These relations present the outputs of the system mentioned above, and will be added to Ao. If the concepts C_1', C_2' insert are not disjoint ($C_1' \perp C_2'$), and have the binary relation(s) with the existing concepts in the base, these relationships will then be added to base as explain in section 4. Furthermore, if the concepts do not exist in the base, we first align these concepts and the results will be added in Ao, in order to be used for relationship alignments, as in the precedent case. Now, if one of the added concepts, have a binary relation with another one within its ontology, then the second one can be inserted with the relationship in Ao if they doesn't exist in the base.

According to the presented approach, the neighbors *Child,Adult* in O_2 will be compared with the neighbor *Male* in O_1 separately(for instance in WordNet: the equivalent synset to: a *Male* is: *male, male, person...*". BRMAP process will infer the relations among the synsets *Male* and *Child*), and add to Ao:{($Male, Adult, \subseteq$)} because ($Male \equiv male\ and\ male \subseteq Child$) . In same way we discovered the relations among the other different concepts of ontologies.

6. Conclusion and perspectives

In this paper we have attempted to propose a new approach of ontology matching. To provide the best result, the approach starts by aligning concepts instances in order to provide ontology alignment and temporary alignment ontology bases. These bases are used as inputs for a second treatment level. The treatment starts by validating the relation of At then aligns the concepts neighbors of Ao, by using terminological method with WordNet. The latter being manipulated by BRMAP as an external khowledge with the anchors denoted by the concepts neighbors, to provide aligned concepts. In this paper an illustrative example of the well-being of the approach is given. The implementation and tests phases using OAEI(Ontology Alignment Evaluation Initiative), are our perspectives.

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